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TRANSLATIONS FROM GEOFIZICHESKAYA RAZVEDKA

(GEOPHYSICAL EXPLORATION), NO. 6, 1961

- USSR -

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This publication contains translations of articles from the Russian-language periodical Geofizicheskaya Razvedka (Geophysical Exploration), No. 6, 1961, on the subjects reflected in the table of contents. Complete bibliographic information accompanies each article.

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THE USE OF HELICOPTERS IN TWO-MILLIGAL

GRAVIMETRIC SURVEYS IN THE TUNDRA

[Following is a translation of an article by B. D. Poletayev in the Russian-language periodical Geofizicheskaya Razvedka (Geophysical Exploration), No 6, Moscow, 1961, pages 47-52.]

In gravimetric surveys in regions that are difficult of access much time and effort are expended in the transportation of the gravimetric detachment along the profile of observations. For two-milligal surveys the output norms during work with a pack are a fourth to a fifth of the norms applied in work with the use of automobiles.

Daily itineraries that are small in extent require the creation of a dense supporting network, which sharply increases the cost of the work. Apart from the high cost of producing an area survey in regions that are difficult of access and sparsely populated, in tundra conditions it is especially necessary to point out great organizational and technical difficulties.

The development of domestic aviation has permitted using helicopters for the performance of work under tundra conditions not only in the presence of the development of a supporting network, but also in the survey of an ordinary network. The use of helicopters is favored by the almost unlimited choice of landing places, adequate radius of their action and smoothness of their landing.

Experimental work on the development of an ordinary gravimetric network with the use of helicopters in two-milligal surveys in regions that are difficult of access was done in 1959-1960 by several geophysical organizations (the Western Geophysical Trust, the Geophysical Petroleum and Coal Surveying Trust, and others) and gave positive results.

We will examine the advantages of such a method of work on the example of the Nechorskaya geophysical expedition, which conducted in 1960 a two-milligal gravimetric survey in the central part of the Bol'shezemel'skaya tundra (director of the party, Yu A Bosykh).

In spite of the high rental cost of a helicopter, its use, as will be shown below on factual material, gives a considerable saving, mainly on account of a sharp increase in labor productivity and reduction in the volume of work in the creation of a dense supporting network.

These operations also considerably raise the quality of the survey, which is linked with decrease in the duration of trips and with favorable conditions of transportation of the instruments. Operations using a helicopter differ from ground operations with a pack by considerable improvement of the culture of the product, working conditions and living conditions of the field detachments. Detachments have the possibility of returning daily to the base of the party, which is completely excluded in operations with a pack. The technical director of the party can daily control the work of all the operators, look after the operation of the instruments, organize timely handling and interpretation of the materials, conduct reasonable detailing, necessary control, etc. All this practically excludes waste in the work and permits reducing to a minimum unproductive expenditures of time and resources.

Let us dwell in more detail on the question of labor productivity. In work with a pack according to the one-time method of observations at two-kilometer intervals a gravimetric detachment should complete 5.8 physical points per shift (VENV, 1951 edition). The actual productivity usually does not exceed 100%, that is, a detachment on an eight-hour trip can make observations at five or six points and tie the trip in to the fixed points.

In work with a helicopter, the sanitary norm of which is five air hours per day, a norm of 22 physical points per shift has been determined for the same conditions during short flights on the basis of a series of photochronometric observations. Thus the productivity per detachment-shift, with different duration, rose in these types of work by almost four times, and the absolute productivity by more than six times.

Along with increase in labor productivity, the reduction of the volume of work in creating a dense supporting network plays an essential role in lowering the cost of a work unit. As work experience with the use of pack transport in making area two-milligal surveys has shown, the necessary density of the fixed points must be not less than one point per 50 - 70 km^2 of area. Only at such a density can the normal fixing of successive trips be assured.

In work with a helicopter the supporting network can be spread out by twenty times or more, and it is sufficient to place the fixed points every 30 - 40 km over a square network. Consequently the costs of creating the supporting network are reduced in the same proportion.

Finally, in helicopter work the staff of the detachment is substantially reduced as regards workers occupied in the transportation of the instruments, packs and other work. The need to hire pack animals also is eliminated. According to the data of the Pechorskaya geophysical expedition the staff of a single detachment is reduced by 15 men, and the need to hire four horses for each detachment is eliminated.

These are the principal sources of cost-reduction of work in two-milligal gravimetric surveys under tundra conditions with the use of a helicopter on a serial network.

Serial networks are completed by the one-time method of observations, with their attachment to fixed points. It is worth while making measurements simultaneously with two gravimetrs to eliminate possible jumps in the readings and reduce the volume of independent control observations. It is desirable to complete an independent control by special trips over routes that intersect the main system of profiles.

In the presence of light MI-1 helicopters, each gravimetric detachment should be equipped with a helicopter, which provides the transportation of the detachment. During the survey the helicopter is landed in the tundra at each point of observations.

In operations with heavy MI-4 helicopters it is worth while making the survey simultaneously with two detachments along adjacent routes. This is connected with the fact that the heavy helicopter cannot land in the tundra at each point. During observations with gravimeters it must, as they say, "hang" in the air. To eliminate such unproductive hanging, a second detachment is included in the work. At the moment when the first detachment is making observations on the point, the second detachment is being transferred in the helicopter to the following point. At the moment of observations by the second detachment the first detachment is making the flight to the following point, and so forth.

This method of working was used in two-milligal surveys on the Pechorskaya geophysical expedition. A considerable rise in the quality of the observations should be mentioned. The mean square error of serial observations in work in helicopters on materials of independent control was reduced by almost half in comparison with the error obtained in work with packs, and was $\pm$ 0.25 milligals.

The normative-research party of the Geophysical Petroleum and Coal Surveying Trust (party director, Ye S Dyukova) has been analyzed and the cost of gravimetric work with use of the MI-1 helicopters has been compared with the cost of work with pack transport in survey of a serial network in the region of the Bol'shezemel'skaya tundra.

An area of 3,150 square kilometers, located to the west of Vorkuta, was taken for analysis, by making a two-milligal gravimetric survey with GAK-3M and GAK-4M instruments. The cost calculations are given in the table.

Calculation of the Cost of Gravimetric Work

Description of work	Cost of work in survey of a serial network (in thousands of rubles)	
	With MI-1 helicopter	With packs
Development of a supporting network with a MI-4 helicopter:		
For aviation work (8 points)	28.3	-
For pack work (53 points)	-	138.0
Survey of a serial network on an area of 3,150 km^2:		
With use of helicopters (21.1 instrument-shifts)	128.6	-
With use of packs (109.3 instrument-shifts)	-	95.5
Total	156.9	233.5
Cost per km^2 of area (rubles) (In values of the ruble prior to 1 January 1961)	49.82	74.13

The economic advantages of using helicopters in surveying serial networks under conditions of Zapolyar'ye are clearly shown. In the example in question the cost of gravimetric survey per km^2 of area is reduced by 48.5%.

A comparison of the estimated cost per 1000 km^2 of area of the 1959 work (when pack transport was used) and the 1960 work (when helicopters were used) was made by the workers of the Pechorskaya geophysical expedition. Although this calculation is not rigorous enough, since total estimated costs of the work of the parties were taken, it is sufficiently indicative.

The cost per 1000 km^2 of survey in 1959 was 363,700 rubles, and in 1960 was 275,700 rubles. Thus the saving in surveying of each 1000 km^2 of area was 88,000 rubles (the cost of the work was determined in the value of the ruble prior to 1 January 1961).

In connection with the unconditionality of the topographic maps on a scale of 1:100,000 for the region of the Bol'shezemel'skaya tundra, the Pechorskaya expedition could not accomplish the planar connection of the points of the gravimetric observations by the method of identification and also use barometric methods of determining the heights of the points. The planar and height connections of the gravimetric points were made by an instrumental method, which somewhat reduced the effectiveness of the use of helicopters in the gravimetric survey, since the topographic work on the ground required large expenditures of time and resources.

For regions for which conditional topographic maps on a scale of 1:100,000 are not provided, it evidently is worth while to use radiogeological methods of planar connection of the points with the establishment of a sonde on a helicopter and to make the survey by gravimeter-altimeters, model GVP-2, or use barometric levelling for the determination of the heights of the points of observations. In the presence of conditional maps and the possibility of determining the planar position of the points by the method of identification, it is worth while using barometric levelling or model GVP-2 gravimeter-altimeters.

In 1960 a survey of a serial gravimetric network was successfully made by the Western Geophysical Trust in the regions of the Malozemel'skaya tundra by means of a helicopter with use of the method of identification and barometric levelling. The method and technique of the gravimetric work did not differ in principle from analogous work, described above, in the regions of the Bol'shezemel'skaya tundra.

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EXPERIENCE IN THE USE OF THE MI-1 HELICOPTER

IN CONDUCTING A GRAVIMETRIC SURVEY

IN CONJUNCTION WITH BAROMETRIC LEVELLING

[Following is a translation of an article by B. P. Borodin, R. G. Kurinin and N. S. Fridlyand in the Russian-language periodical Geofizicheskaya Razvedka (Geophysical Exploration), No 6, Moscow, 1961, pages 52-59.]

The conducting of a two-milligal gravimetric survey with a scale of 1:200,000 on large areas under conditions of Karyneye Severo was associated with considerable organizational and technical difficulties, and also with large monetary expenditures. Great distance from populated points, the complete absence of roads and the swampiness of the terrain complicate the movement of ground detachments and the supplying of food to them and sharply reduces labor productivity.

In 1959 the Nar'yanmarskaya gravimetric party of the Western Geophysical Trust undertook to carry out a two-milligal gravimetric survey on a scale of 1:200,000 of a region of the Malozemel'skaya tundra. In connection with the above-indicated difficulties, an MI-1 helicopter was used by the party in the survey of a serial network in order to ease the working conditions, increase productivity and lower the costs of the work.

The use of the helicopter was favored by the open flat country of the tundra and forest-tundra, a large number of lake reference points and the excellent flying qualities of the helicopter: an almost unlimited selection of landing places, smoothness of landing and a considerable radius of action.

In 1959 the survey was completed on previously levelled profiles, on which the observation points were fixed with small white flags. Finding such a profile from the air during flight of the helicopter at 100 - 150 meters caused no special difficulties. These operations showed great prospects for the use of the MI-1 helicopter in a gravimetric survey under the conditions of the tundra of Krayneye Severo.

However the use of ground topogeodetic work with low productivity sharply reduced the effectivness of the use of helicopters in the gravimetric survey. For the purpose of increasing the effectiveness of this work, in 1960, on an area of 13,000 km^2, a gravimetric survey was made in a complex with barometric levelling by means of an MI-1 helicopter. The planar connection of the points of the gravimetric observations was accomplished by the method of identification on maps with a scale of 1:100,000, with use of the materials of an aerial photographic survey.

The base of the party, with a fuel and lubricants warehouse for servicing of the helicopter, was organized at about the center of the survey section. A fixed point of increased accuracy was established at the base of the party, connected with the Bulanzhe point by direct connections.

The radius of action of the MI-1 helicopter, with landings at observation points every two kilometers and with flight to the fixed point taken into consideration, was 60 - 70 kilometers. In this connection the entire section of the survey was worked from a single starting point (the base of the party), on which all the serial trips were started and completed.

It should be noted that increase in the radius of action of the helicopter, and consequently increase in the area of the survey, can be attained by creating additional sub-bases with fuel and lubricants warehouses in the tundra, where the helicopter can be provided with fuel directly on the route without returning to the main base.

The length of the serial trips in working with the helicopter was four to five hours. The change in temperature of the instruments during that interval of time usually did not exceed 1.0 - 1.5° and only in individual cases reached 2.0 - 2.5°. The displacement of the zero point of the instruments was insignificant. The mean square error obtained in the serial measurements was $\pm$ 0.25 milligals, which is evidence of the high accuracy of the survey. The accuracy of the determination of anomalies was $\pm$ 0.6 milligals. The materials of the field measurements, after the daily return of the helicopter to the base, were processed at once by the office group, which permitted direct control of the quality of the survey. The productivity of a single instrument-shift for one servicing of the helicopter was 15 - 20 points, which is more than three times the productivity of ground work. The working up of the serial network was done with one or two GAK-3M gravimeters. Labor productivity was reduced somewhat when the work was done with two gravimeters. However, in that case the reliability of the determination of the force of gravity at each point was increased, and the need to include in each trip an intermediate point was eliminated, which considerably reduced the number of control measurements. The method of working with two gravimeters in a survey with a helicopter with a radius of action up to 70 km thus permits processing an area of about 10,000 - 12,000 km^2 from a single starting point without developing a supporting network on the entire area of operations. Upon increase in the area of the survey, when it will be necessary to create additional sub-bases with stores of fuel and oil for servicing the helicopter, which must be processed as fixed points and connected into a single supporting network, such a network will be uncommon and large expenditures of time and resources will not be required in creating it.

The Method and Technique of Barometric Levelling

Determination of the absolute heights of the points of the gravimetric observations, with a mean square error of $\pm$ 2.5 meters, entered the task of barometric levelling. Before the start of productive work, test barometric levelling trips were made in a MI-1 helicopter on points of a levelled network of classes III - IV. The test trips permited checking the method and technique of barometric levelling, and suitability of the instruments for work under tundra conditions with the use of air transportation.

Besides the test work, a comparison was made of the data of a barometric levelling with the data of a geometric levelling on one of the routes of the gravimetric survey. Comparison of the absolute heights of the points of a leveled network of classes III - IV and of the points of a geodetic levelling with the heights of the same points, obtained by the method of barometric levelling, made it possible to estimate the accuracy of the method and dispense completely with expensive instrumental work.

In making the barometric levelling, a method of closed trips with the use of the readings of several permanent meteorological and of temporary stations (control barometers) was worked out. On the working section and beyond its limits observations were made daily of the atmospheric pressure and the temperature of the surrounding air at six meteorological stations of the Northern Hydrometeorological Service and of two temporary barometric stations of the party, one of which was combined with the base of the party. The distance between the meteorological stations did not exceed 100 km on the average.

The atmospheric pressure was measured every thirty minutes each day, and the temperature of the surrounding air every hour from 0800 to 2000 Moscow time. The results of the observations were recorded in special journals, copies of which were sent to the address of the party. The absolute heights of the zeros of the station barometers were obtained by technical levelling.

The number of stations and their location with respect to the work section were such that any route of the gravimetric survey that could be worked out was within triangles at the apexes of which permanent or temporary meteorological stations were located. Such a position of the work section in relation to the meteorological stations to a considerable degree excluded the influence of non-equilibrium of the atmospheric pressure on the accuracy of the barometric levelling and permitted establishing the absolute heights of the points of the gravimetric survey with adequate accuracy.

The barometric levelling was done exclusively by closed trips with a duration of five to six hours. The starting and ending points of each trip were permanent or temporary meteorological stations. To determine the supplementary corrections, before and after each trip all the field aneroid barometers were compared with mercury barometers. To increase the accuracy of the measurements, the pressures were measured simultaneously with six aneroids, and the average of the six was adopted in the processing, if they did not differ by more than 0.6 mm. The temperature of the surrounding air was measured by means of psychrometers. For field work, aneroid barometers with temperature coefficients close to zero and with supplementary corrections not exceeding 2 - 3 mm Hg were selected.

During the period of operations the change of these corrections per day (trip) did not exceed 0.2 - 0.3 mm Hg on the average, and for the six months of the field season, 1 - 2 mm Hg. All the instruments had been checked by the Central Checking Bureau (Tsentralnoye byuro proverki) at the Main Geophysical Observatory im Voyeykov (Glavnaya geofizicheskaya observatoriya im Voyeykova) and had checking documents. Under productive conditions the aneroids were kept in specially constructed suitcases, three apiece, and were transported in the cabin of the helicopter. For stabilization of the temperature of the aneroid barometers the insides of the sections of the suitcases were lined with a layer of cotton. For this purpose each section was provided with a glass cover. The temporary meteorological stations of the party were equipped with two inspectional (mercury) barometers, a psychrometer and a radio station. The atmospheric pressure was determined simultaneously with two mercury barometers and the average of their readings was taken if they did not differ by more than 0.3 mm Hg. The mercury barometers were kept in special cases suspended on immobile objects (columns or walls of buildings). The processing of the materials of a trip began with calculation of the supplementary corrections of each aneroid, which were spread proportionally over the whole trip.

The calculation of the absolute heights was done with use of the readings of two or three meteorological stations independently of each point of the survey.

For control of the height, a series of points were calculated on different triangles or lines of directions of the stations. In these cases the deviations as a rule did not exceed 1 - 2 meters.

The absolute heights of the points of the supporting gravimetric network were obtained by barometric levelling in the process of its development as the mean values of three or four determinations by six aneroids, made independently of the trips. The results of calculation of the heights of some fixed points, obtained under different atmospheric conditions, are given in Table 1.

Table 1

№ пункта (1)	Дата наблюдений (2)	Абсолютные высоты (3)	Отклонения от среднего значения (4)
ОП-21 (6)	17.VII—60 г.	34,28	—0,52
	13.V—60 »	34,93	—1,17
	10.VI—60 »	32,06	+1,70
	(5) Среднее значение	33,76	
ОП-22 (7)	17.IV—60 г.	24,10	—2,26
	19.IV—60 »	22,55	—0,71
	4.V—60 »	21,51	+0,27
	27.V—60 »	19,71	+2,13
	27.VI—60 »	20,45	+1,39
	(5) Среднее значение	21,84	
ОП-17 (8)	17.IV—60 г.	56,26	—0,71
	27.V—60 »	58,40	—0,85
	10.VI—60 »	58,24	—0,69
	22.VI—60 »	57,37	+0,18
	24.VI—60 »	55,46	—2,09
	(5) Среднее значение	57,55	

1 - Point No; 2 - Date of observations; 3 - Absolute height; 4 - Deviation from average value; 5 - Mean; 6 - OP-21; 7 - OP-22; 8 - OP-17.

The absolute heights of the points of a serial survey were obtained from single trips. However, their quality was controlled by subsequent independent trips.

On the entire area of the survey, 1335 points were processed, of which 160 were controlled, which is 12% of the total number of points. The results of the control determinations of the heights by barometric levelling, and also an estimate of the accuracy of the method in comparison with geometric and technical levellings, are given in Table 2.

If we analyze the results of the work on the barimetric level-

Table 2

	Всего 2	Расхождения значений высот, полученных методом баронивелирования (в м) 1								
		до 0,5	0,5—1,0	1,0—1,5	1,5—2,0	2,0—2,5	2,5—3,0	3,0—3,5	3,5—4,0	Свыше 4,0 3
4 С данными геометрического нивелирования										
Количество определений 7	14	3	2	6	2	1	—	—	—	—
% распределения ошибок 8	100	22	14	43	14	7	—	—	—	—
9 Средняя квадратическая ошибка определения высот баронивелированием по твердым пунктам ±1,26										
5 С данными технического нивелирования										
Количество определений 7	47	15	9	6	8	3	3	2	1	—
% распределения ошибок 8	100	32	20	13	17	6	6	4	2	—
10 Средняя квадратическая ошибка определения высот баронивелированием по твердым пунктам ±1,53										
6 С данными контрольных баронивелирных определений										
Количество определений 7	110	17	19	19	17	9	12	8	2	7
% распределения ошибок 8	100	15	17	17	15	8	11	8	2	7
11 Средняя квадратическая ошибка определения высот баронивелированием ±1,86										

1 - Deviations of the values of the heights obtained by barometric levelling (in meters); 2 - Total; 3 - Above 4.0; 4 - Comparison with the data of geomteric levelling; 5 - Comparison with the data of technical levelling; 6 - Comparison with the data of control barometric levelling determinations; 7 - Number of determinations; 8 - Percentage distribution of errors; 9 - Mean square error of determination of heig ts by barometric levelling on fixed points ± 1.26; 10 - Mean square error of determination of heights by barometric levelling on fixed points ± 1.53; 11 - Mean square error of determination of heights by barometric levelling ± 1.86.

ling it can be said that the attained accuracy of determination of absolute heights of points of the gravimetric survey under conditions of tundra relief with the use of air transport satisfies the requirements for two-milligal gravimetric surveys.

As a result of the introduction into production in 1960 of a gravimetric survey on an MI-1 helicopter in a complex with barometric levelling, the actual cost of one km^2 of survey was reduced from 138 rubles in 1959 to 98 rubles in 1960, that is, an annual saving of 520,000 rubles (in values before 1 January 1961) on an area of 13,000 km^2.

The above-described method and technique of gravimetric survey with an MI-1 helicopter in a complex with barometric levelling are the most rational under the tundra conditions of Karyneye Severo and have the following advantages: the organization of the production of work is simplified, the accuracy of the survey is increased, labor productivity is sharply increased and the cost of the work is reduced.

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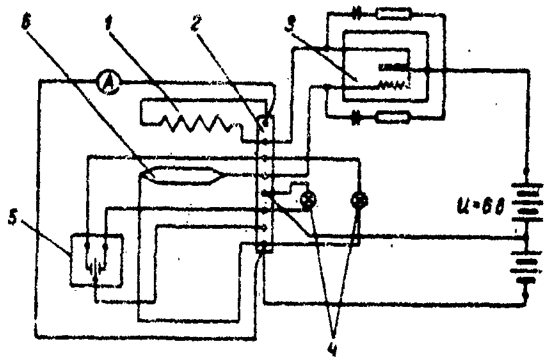
THE GAK-3M GRAVIMETER WITH ELECTRICAL THERMOSTAT

[Following is a translation of an article by A. N. Timofeyev and V. N. Rosenberg in the Russian-language periodical Geofizicheskaya Razvedka (Geophysical Exploration), No 6, Moscow, 1961, pages 93-95.]

The Yakutsk geological administration (Yakutskoye geologicheskoye upravleniye) has conducted detailed gravimetric surveys with the serially-produced GAK-3M gravimeter. For these surveys it was required to increase the accuracy of the instruments and their stability in operation, since increased accuracy of the survey is worth while under the conditions of Yakutiya at the expense of complication of the method in view of the great additional costs.

The serial trips under severe taiga conditions in a sparse network of fixed points have a large duration (10 - 12 hours). In the course of this time the air temperature usually changes a great deal and also the temperature within the instrument. The change in the latter is taken into consideration with insufficient accuracy, and this brings about basic errors in the measurements. To reduce errors the instrument is previously prepared by adding identical change of temperature of the instrument in the trip, that is, it is heated or cooled.

However, on large trips it is almost impossible in practice to keep the value and linear change in temperature of the instrument constant. For the purpose of creating a constant temperature regime, S P Popov has designed a simple electrical thermostat. It has been established that the principla heat exchange occurs through the upper panel of the gravimeter, since the Dewar vessel adequately insulates the quartz system from the effect of the outside temperature. Therefore the electrical thermostat was placed between the upper panel and the body of the elastic system. Experiments have shown the correctness of this solution. The conductor of the thermostat (with a resistance of 22 - 25 ohms) is wound with 8 - 10 turns on an aluminum form placed on a protective cylinder. The thermostat is connected with a contact thermometer, relay, ammeter and power source (see the figure) by a connecting panel. The connecting panel is located on



Electrical circuit of the thermostat. 1 - Furnace (R = = 22 - 25 ohms); 2 - Connnecting panel; 3 - Relay; 4 - Dial-lighting lamp; 5 - Switch; 6- Contact thermometer.

the upper cover of the instrument. The contact thermometer is put in a special socket of the aluminium form and is connected to the connecting panel through an additional opening in the upper panel. The relay is fastened either on the Dewar vessel or in a single housing with the power sources. The ammeter is led out on the cover of the instrument. In the assembling of the circuit, contact thermometers from SN-3 or GV-52 gravimeters and a relay from an SN-3 gravimeter were used. The power sources were dry cells or 32NKN-2.25a batteries. They were combined in a group that had a voltage of 6 V and were placed in a special housing fastened to the housing of the instrument. The battery unit lasted for five to seven trips even when the outside and inside temperatures fell 20 - 30°. Under winter conditions, dry cells were used for the most part, because the other batteries froze. The described device did not substantially change the weight and dimensions of the instrument, which was especially important under the severe conditions of transport. The power sources likewise did not involve the actions of the operator.

The first trips with a gravimeter equipped with an electrical thermostat were made in 1957 and gave excellent results. In 1958 and 1959 a one-milligal survey with a scale of 1:100,000 was conducted. It was made in the summer at an air temperature of up to +30-35° C, and in the autumn, spring and winter when the frosts reached -40° C and lower. In spite of such large temperature drops the temperature within the instrument varied by not more than 0.1 - 0.2° C.

Thanks to being equipped with the thermostat the zero point of the gravimeters was considerably reduced and became more linear. With the same method of survey and a large duration of the trips (up to ten or twelve hours) the accuracy of the observations rose considerably. The error of observations of the serial network on materials of independent control were ± 0.28 milligals in the winter period. In the summer period the accuracy reached ± 0.21 milligals.

At the present time, one-milligal surveys are being conducted in large volume in Yakutiya with GAK-3M gravimeters equipped with electrical thermostats.

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ON THE ACCURACY OF ALTITUDE DETERMINATIONS

FROM TOPOGRAPHIC MAPS DURING REGIONAL GRAVIMETRIC SURVEYS

[Following is a translation of an article by A. P. Yegorov in the Russian-language periodical Geofizicheskaya Razvedka (Geophysical Exploration), No 6, Moscow, 1961, pages 118-124.]

The making of gravimetric surveys is connected with large expenditures for the creation of a geodetic base, especially in the regions of Siberia and the Far East that are difficult of access. To reduce the cost of these operations, the productive geophysical organizations are using topographic maps for determination, according to them, of the coordinates and altitudes of gravimetric points.

The accuracy of the determination of the altitudes of these points will depend on the quality of the topographic maps used, their scale, the character of the relief of the locality, the presence of an adequate number of reliable orienting points, etc. All this must be taken into consideration in the planning and conduct of the work, as even those relatively low requirements set for the accuracy of the geodetic base in regional gravimetric surveys can be unfulfilled if any one of the enumerated factors is not considered.

In the present article we examine the combined influence of errors of the planar and altitude positions of gravimetric points in determining their altitudes according to topographic maps, and the conclusions drawn can serve as a precaution against errors in counting during the use of those maps for the above-mentioned purposes.

The error in determination of altitudes of gravimetric points according to undeformed topographic maps (m_H) depends on the error in representation by means of the horizontal relief of the locality and on the error in the plotting by the topographer of the gravimetric point on the topographic map:

$$m_H^2 = m_h^2 + m_e^2,$$

where m_h is the mean square error of representation on the map by means of the horizontal relief of the locality; m_t is the mean square error in the altitude of the point, connected with the error of its plotting on the map.

Let us establish the values of each of these errors.

I. The error of representation of the relief on the map by means of the horizontal depends on the error in position of the horizontal in altitude with respect to the altitude support m_1 and the error of interpolation between the horizontals at the height m_2:

$$m_h^2 = m_1^2 + m_2^2.$$

In accordance with the instructions and directions for topographic surveying in effect prior to 1949, the error of position of the horizontals in height with respect to the observed points of the support can attain the values indicated in Table 1.

Table 1

Угол наклона, град. 1	Ошибка в положении горизонталей 2
До 2 3	$^1/_4 h$
» 5	$^1/_2 h$
» 7	$^3/_4 h$

Note: h is the height of the basic section. 1 - Angle of inclination, degrees; 2 - Error in position of the horizontals; 3 - Up to 2.

For maps with scales of 1:100,000, 1:50,000 and 1:25,000 these errors are expressed in the values given in Table 2.

Table 2

Масштаб карты 1	Основное сечение 2	Ошибка положения горизонтали, м 3			
		до 2°	до 5°	до 7°	7°
1 : 100000	20	5	10	15	20
1 : 50000	10	2,5	5	7,5	10
1 : 25000	5	1,3	2,5	3,6	5

1 - Scale of the map; 2 - Basic section; 3 - Error of position of the horizontal, meters.

In January 1956 "Basic Positions in the Creation of Topographic Maps with Scales of 1:10,000, 1:25,000, 1:50,000 and 1:100,000" were approved as obligatory for all institutions conducting topographic surveys and the compilation of topographic maps; in it the following (Table 3) values were established for the mean errors of representation on a map of relief by means of horizontals (#15).

Table 3

Районы съемки	m_1 — средняя ошибка положения горизонталей, м		
	1:25000	1:50000	1:100000
Плоско-равнинные	1	3	6
Равнинные, пересеченные и всхолмленные с преобладающими углами наклона до 6°	2	4	9

1 - Survey regions; 2 - m_1 - the mean error of position of horizontals, meters; 3 - Flat lowlands; 4 - Plains intersected and with hills, with predominant angles of inclination up to 6°.

For mountainous and enclosed terrain the indicated allowances are doubled.

The mean square error of interpolation between pegs in drawing horizontals on a plane according to Bakstrem (Oshibki nablyudatelya pri otschityvanii po shkalam izmeritel'nykh priborov - The Observer's Errors in Taking Readings on the Scales of Measuring Instruments -- Moscow-Leningrad, 1934) is, in meters:

$$m_2 = 0.012\ M + 0.035\ d,$$

where M is the number of thousands in the denominator of the scale of the plane, and d is the distance between the pegs in meters.

For the case of interpolation of a point between horizontals in height, this formula can be presented in the following form:

$$m_2 = 0.012\ M \tan \nu + 0.035\ h,$$

where h is the basic section, in meters, and ν is the angle of inclination.

For the map scale 1:100,000 and h = 20 meters, the average error of interpolation between the horizontals will be m_2 = 1.0 m and m_2 = 2.0 m at ν = 2° and ν = 6° respectively. Hence on the basis of of comparison of the data of Table 3 with the results obtained it follows that m_1 exceeds m_2 by more than three times. Consequently, the total error in height of the determined point m_h will be equal to m_1 with an error of 2%.

II. The accuracy of plotting of the gravimetric point on the map depends on the error of identification of the pont with respect to the contour on the map (m_3) and the error in position of the same contour on the map m_4:

$$m_e^2 = m_3^2 + m_4^2.$$

The error of identification on the map depends on the method of determining the location of the gravimetric point relative to the contours of the locality.

Several methods of planar connection to the contours of the map are used in a gravimetric survey: a) the instrumental method; b) identification by large scale aerial photos visually and transfer of the identified point to the map; c) identification on the map visually.

Each of these methods gives a different accuracy of determination of the planar position of gravimetric points. The instrumental method, when the contours are expressed with sufficient clarity, does not introduce additional errors, since the error in the plane will be equal to the graphic error in transfer of the position of the determined point onto a map with a scale of 1:100,000, that is, $\pm$ 0.2 mm.

In the identification of the gravimetric point by aerial photographs, the error in planar position does not exceed the graphic accuracy of transfer of that point to the map if an aerial photograph with a larger scale than that of the map is used. Thus, if an aerial photo with a scale of 1:25,000 is taken with an average error of identification of $\pm$ 0.05 mm in the scale of the photograph, the total error of determination of the planar position of the point by this method will equal $\pm$ 0.22 mm on a map scale of 1:100,000.

The largest error can be expected in visual identification of a gravimetric point on a map. The mean error for excellently expressed contours in the best case will be $m_3 = \pm 0.5$ mm, and in the presence of poorly expressed contours and in an enclosed locality $m_3 = \pm 0.8$ mm of the map scale.

Finally, let us consider error in the position of the contour itself on the map, m_4.

The value of this error is composed of:

1) Errors in the position of the fixed points m_5 (for well expressed contours equal to $\pm$ 0.1 mm and for a closed locality $\pm$ 0.2 mm;

2) Errors in the position of the contour points relative to the points of the geodetic base m_6 (for well expressed contours $\pm$ 0.5 mm and for closed regions $\pm$ 0.8 mm;

3) Errors of the graphic processes in making up the maps m_7, equal to $\pm$ 0.2 mm.

These errors can be considered random, since the combined effect of them is determined as a function of the total error:

$$m_4^2 = m_5^2 + m_6^2 + m_7^2.$$

Then the mean error in position on the map of objects and contours of the locality with respect to the closest points of the planar survey network will equal:

For well expressed contours, $m_4 = \pm$ 0.5 mm; for mountainous and closed regions, $m_4 = \pm$ 0.8 mm.

And so the total error in the plane m_e will amount to:

For well expressed contours

$$m_e = \pm\sqrt{0{,}5^2 + 0{,}5^2} = \pm 0{,}7 \text{ мм};$$

For mountainous and closed regions

$$m_e = \pm\sqrt{0{,}8^2 + 0{,}8^2} = \pm 1{,}2 \text{ мм}.$$

The error in the plane is in direct dependence upon the angle of inclination of the locality and the map scale:

$$m_e = \sqrt{m_s^2 + m_4^2}\ \operatorname{tg} \nu M,$$

where M is the thousand denominator of the scale.

Tables of the total errors in determination of the heights of gravimetric points on the horizontals of topographic maps (in meters) have been presented. The mean errors in determination of heights on topographic maps for regions with well expressed contours are given in Table 4.

Table 4

Масштаб карты (1)	Основные сечения (2)	Уклон местности (3)					
		до 2° (4)			до 6°		
		m_h	$m_в$	m_H	m_h	$m_в$	m_H
1 : 100000	20	6,0	2,4	6,4	9,0	7,6	11,7
1 : 50000	10	3,0	1,2	3,2	4,0	3,8	5,5
1 : 25000	5	1,0	0,6	1,4	2,0	1,9	2,8

1 - Map scale; 2 - Basic sections; 3 - Inclination of locality; 4 - Up to 2°.

The mean errors in determination of heights on topographic maps for enclosed regions are given in Table 5.

Table 5

Масштаб карты (1)	Основные сечения (2)	Уклон местности (3)					
		до 2° (4)			до 6°		
		m_h	$m_в$	m_H	m_h	$m_в$	m_H
1 : 100000	20	12,0	4,2	12,7	18,0	12,7	22,0
1 : 50000	10	6,0	2,1	6,3	8,0	6,3	10,1
1 : 25000	5	2,0	1,0	2,2	4,0	3,1	5,0

1 - Map scale; 2 - Basic sections; 3 - Inclination of locality; 4 - Up to 2°.

It can be concluded from the tables that it is possible to use maps for determining the heights of gravimetric points only under the following limited conditions:

1. It is impossible to use topographic maps with a scale of 1:100,000 for determinations of heights in gravimetric surveys with scales of 1:500,000 and 1:200,000 and larger.

2. In plains regions (with an angle of terrain up to 2°) with well expressed contours it is possible to find the heights of gravimetric points on topographic maps with a scale of 1:50,000 in gravimetric surveys on a scale of 1:200,000.

If the contours of the terrain are not clearly expressed and the angle of inclination do not exceed 4 - 6°, the use of maps with a scale of 1:50,000 is possible under conditions of instrumental methods of connection of identified points to the geodetic support or to clearly expressed contours of the terrain, and also of aerial photos of a much larger scale.

3. It is possible to use topographic maps with a scale of 1:25,000 for determination of the heights of gravimetric points with a survey scale of 1:500,000 and 1:200,000.

The experience of the work of the gravimetric parties of the Geophysical Petroleum and Coal Surveying Trust (trest Geophixnefte-uglerazvedka) confirms the above conclusions. In Table 6 are the mean square errors in determination of heights on maps with a scale of 1:50,000, obtained by control determinations on 201 points by gravimetric party 18/60, who conducted work in the inhabited rayons of the Kalininskaya oblast (points attached to strict orienting points).

Table 6

Угол наклона, град. (1)	Количество пунктов (2)	Среднеквадратическая ошибка определения высот по картам масштаба 1 : 50000, м (3)
0—1	50	±1,1
1—4	110	±1,6
4—7	41	±1,9

1 - Angle of inclination, degrees; 2 - Number of points; 3 - Mean square error in determination of heights on maps with a scale of 1:50,000, in meters.

The conclusions drawn relate to conditioned maps (composed on a geodetic base of full value).

In the regions of Krayneye Severo and Siberia, maps are compiled on a thinned out geodetic base, and therefore it is impossible to determine heights with these maps.

In confirmation of what has been said it is necessary to refer to the work of the Northern Siberia geophysical expedition of the All-Union Scientific Research Institute of Geophysics (VNIIGeofiziki. Since 1955 regional gravimetric surves have been conducted by the expedition in various rayons of Siberia, in which heights have been determined by barometric levelling.

If we analyze the results of comparison of the heights of the gravimetric points determined by various methods (by levelling, by the maps, and by barometric levelling), it has been made clear that the errors in the heights, obtained by topogeodetic maps with a scale of 1:100,000, reach 30 - 40 meters and more.

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